Chapter 5, Section 2b

Effects of Magnetic Fields on Animal Behaviour

by

M. A. Persinger

There are at least two methods by which a locked door can be opened: by using the appropriate key or by breaking the lock. Both techniques achieve similar results—the door opens. The former method requires very little energy, the latter requires a great deal more. However a door with a broken lock may behave differently from a door with a functional mechanism. This analogy can be used to illustrate some of the most central and pressing issues of biomagnetic research. What is the magnetic field configuration that will open the organismic lock? Are there optimal NATURALLY occurring magnetic field intensities, frequencies and geometries that can unlock the organismic door? Do the configurations of these locks vary with the nature of the organism and system exposed? These questions are complicated by the interacting and intervening variables of: (1) short versus long term exposure differences, (2) respondent versus operant behaviour measurements, (3) stage of development during exposure, (4) stimulus operations performed on the organism before exposure, (5) interfering extraneous magnetic ambients and (6) isolation of a physical mechanism.

The methodology by which bio-effective magnetic field configurations can be determined is influenced by two approaches. One approach emphasizes that natural magnetic field frequencies, intensities and geometries should be simulated as closely as possible to produce optimal effects. A second approach assumes that a biomagnetic effect, if it exists, should be amplified by increasing the intensities of applied fields to extremely large values. This last position presumes that sufficient field intensities must be maintained to compensate for such processes as thermal agitation. An approach of this type reflects not only a theoretical framework which influences much of biophysical research, but also a mentality. There seems to be an implicit assumption among a variety of experimenters that the larger the intensity, the larger the effect. The possible existence of a biochemical reaction with narrow band specificities for magnetic field intensity and frequency is apparently not considered by such individuals.

Occurrence of specific vectorial configurations that provide maximum stimulation to bioelectrical systems would make sound evolutionary sense. It would be unfeasible as well as unadaptable, to respond to just any electrical or magnetic stimulus. Moreover, the susceptibility to magnetic field stimulation would optimally be related to a state-dependency or organismic-predisposition such that responses could be limited in their occurrence to specific instances related to adaptability. Possible state-dependencies would be the physiological changes displayed during flight in birds or hormonal changes in animals before migration or homing. The monumental work of Brown (e.g., 1966) has demonstrated that maximum modification of snail behaviour occurs with intensities that closely approximate the geomagnetic field. Becker (1967) reported similar effects with insect orientation. Several researchers have failed to experimentally support the

frequently postulated thesis that magnetic fields may be used in migratory/homing behaviour in birds. Most of these studies have used field parameters which were either higher in intensity or substantially different in spatial-temporal configuration than natural geomagnetic patterns. Wiltschko (1968) has emphasized that migratory-related behaviours in static artificial magnetic fields were not significant unless the strength approximated that of the earth.

However, neither life nor environmental forces are characterized by static processes—both show temporal properties. Much of the time-varying processes in both life forms and geomagnetic-related occurrences occupy a relatively narrow band with periods of a few minutes to a hundreth of a second (100 Hz). Extremely low frequency (ELF) electromagnetic phenomena have been defined as time-varying field-waves produced in organisms or in the environment between 0.01 Hz to 100 Hz (Persinger et al., 1973). Other definitions of the ELF wave band overlap these frequencies. The ELF range includes electromagnetic signals from autonomic neurons to more global brain sources such as those measured by the electroencephalogram. Power output (EEG) from the brain shows peaks around 10 Hz. In nature, similar electromagnetic frequency bands are associated with solar disturbances, frontal (weather) movements and even a terrestrial resonance system (the Schumann resonance). Biogenic electromagnetic variations of lower frequencies are measured in minutes or hours and include d.c. potentials. Ambient magnetic perturbations associated with geomagnetic storms overlap these organismic fluctuations. Time-variation in electromagnetic processes is an intrinsic component of life forms. Ignorance of these frequency ranges in experimental research has led and will lead to premature dismissal of possible biomagnetic effects.

Very often time-varying magnetic fields and static fields of comparable intensities have opposite or different effects. Lazar and Barca (1969) noted that small intensity pulsating magnetic fields decreased sodium ions but increased potassium ions in tissue while a static field had opposite effects. Intermittent fields can delay hatching in ducks and produce unfavorable changes in albumin biosynthesis while a static field of comparable intensities has no such effect (e.g., Ossenkopp, and Shapiro, 1973; Barndsch and Jitariu, 1971). The time factor in magnetobiological effects is indeed a critical feature.

Existence of different reaction patterns to different types of magnetic fields would suggest magnetic field-organismic equivalents of a lock and key mechanism so often postulated for agonist-receptor site dynamics in drug interactions. Large or exaggerated "magnetic keys", typified by high intensity static magnetic fields, merely break or force the "lock". However, other more complex "magnetic keys" with appropriate frequency, intensity and spatial configurations that simulate biogenic magnetic field analogs of the organism would show the greatest effectiveness. The existence of such a hereto, unacceptable parameter specificity for magnetic field-organismic relations has been given strong support by the experiments of Becker (1972). Becker contends that there exists in living tissues an extremely narrow range of effective current densities in the $m\mu$ amp region. Intensities below the optimum are predictably not effective; those above are ineffectual or destructive.

Much confusion often arises by mistakenly equating two different questions: (1) can

the organism detect a magnetic field, (2) can a magnetic field affect the organism? The answers to both questions are not necessarily commensurate. Various studies with birds of different species have failed to produce any consistent evidence that magnetic fields may act as conditioned stimuli (CSs) to either the delivery of positive or aversive stimuli. Grisset and De Lorge (1971) and Marr et al. (1973) have also failed to discern in several species any behavioural changes that indicate ELF magnetic fields of 45 or 75 Hz can act as conditioned stimuli (cues) to the consequent occurrence of shock or simultaneous availability of food. Scattered Soviet works on glial cell activity have been reported, suggesting changes in electrical potentials with a slight latency of a few minutes (e.g., Travkin, 1972).

On the other hand, longer term exposure to magnetic fields for continuous or repeated short durations results in a variety of behavioural and physiological changes. With static fields of intensities ranging from 10 to 5000 gauss, changes in visceral organ weights, endocrine chemicals and susceptibility to disease have been repeatedly mentioned. Reactive glial changes have been reported by Soviet scientists but not by others, (e.g., Friedman and Carey, 1969). Adult rats exposed to 0.5 Hz rotating magnetic fields (RMFs) between 0.5 to 50 gauss from 5 to 30 days show significant changes in water consumption, thyroid weights, and body weights, (Persinger et al., 1973). Removal of animals from the RMFs resulted in increased ambulation, specifically in male rats. Pulsatile fields between 130 μsec. to 3 sec. at intensities up to 300 gauss for periods of 1.5 hrs per day for 30 days to more continuous exposures have been reported to affect G-6-P activity, ATP/ADP ratios, serum glutamic oxaloacetic transaminase levels and follicle size (e.g., Porumb, 1971; Neaga and Lazar, 1972). Generally these effects take at least 2 to 5 days before they appear, thus suggesting a stress-like reaction in the animal. Two separate unpublished studies by Persinger (1967) and LaForge (1972) imply that exposure of rats to 0.2-0.5 Hz fields between learning situations may interfere with display of appropriate behaviours. Rats exposed to 8000 gauss fields after conditioned avoidance training have been reported to show a delay in criterion learning (Meszaros et al., 1971). However, these effects may be more indirectly due to competing ambulatory behaviours related to the paradigm rather than direct interference with presumed electrical correlates of memory consolidation.

The problem of detectability of magnetic fields is not unrelated to the behaviour measured. Experimental psychology underwent a period of confused comparisons between ambulatory behaviour, which is displayed in mazes and open fields, and discrete response behaviour, which is emitted in operant chambers. Experimental manipulation of stimulus patterns did not always produce comparable results in both types of behaviour. Different motoric and ancillary systems are involved with ambulatory and discrete response behaviour.

Similarly, responses associated with the autonomic nervous system are not necessarily comparable to those associated with the somatic (skeletal) nervous system. Autonomic system reactions involve smooth muscle modifications and are more susceptible to the effects of classical (respondent) conditioning. With this type of conditioning, the major stimulus (UCS, i.e., unconditioned stimulus) elicits (is followed by) a response. Repeated pairings in time and space of a previously ineffective stimulus with the UCS

can result in the occurrence of a response when the previously ineffective stimulus (now the conditioned stimulus or CS) is presented by itself. An animal in this situation maintains a relatively passive role to a series of CS-UCS pattern presentations. On the other hand, the skeletal system seems more susceptible to operant conditioning. This paradigm makes the delivery of the reinforcer (a UCS or CS) more directly dependent upon the animal's behaviour, such as a lever press.

Experiments by de Lorge (1972) and Marr et al. (1973) with 7 Hz, 10 Hz, 45 Hz, 60 Hz and 70 Hz, 2-3 gauss magnetic fields almost conclusively demonstrate that the behaviour of monkeys, rats and pidgeons maintained on a variety of operant schedules does not show consistent variations when these fields are present. One could argue that the stimulus control of the reinforcement schedule would not be appreciably disrupted by such relatively weak stimuli. Behaviours maintained on some schedules of reinforcement are remarkedly immune to any large perturbations by extraneous stimulation. However, these authors have also attempted using ELF fields in a conditioned suppression paradigm as a cue to the later onset of electric shock. With normal stimuli (e.g., light), a few pairings of antecedent light followed by shock results in the suppression of ongoing food associated lever responding during the light presentation. The ELF fields used in these studies were not effective as "warnings" to aversive stimuli, since animals would continue responding during their presentations.

These results do not eliminate the possibility that whereas lever pressing (discrete) behaviours were not affected by short term ELF field presentations, other systems were responsive but not measured. Two studies which have used an autonomic response (heart rate change) as their dependent measure in a classical conditioning paradigm have produced more positive results. Reille (1968) noted that pidgeons exposed for 5 sec. to weak (0.15 gauss), 0.3 Hz, 0.5 Hz and higher frequency fields before the onset of an electric shock, began to show increases in heart rate after the presentation of the field but before the shock. Yakovleva and Medvedeva (1972) have shown similar cardiac conditioned responses to a constant magnetic field of 520 gauss presented before shock. Although recent work with biofeedback has shown that autonomically innervated organs may indeed be susceptible to operant control, the distinction between autonomically controlled and non-controlled behaviours should be realized when studies of magnetic field detectability are involved.

Organisms in different developmental stages may show differential responses to the same stimuli. Certainly the numerous experiments with the effects of ionizing radiation should emphasize the importance of this variable. During prenatal and to some extent neonatal-juvenile development the organism displays a remarkable plasticity and production. Neurons leave their proliferative matrices and travel to destinations by mechanisms which are not entirely clear. Chemical reactions which will result in the critical biochemical pools of the brain are in progress. One would suspect that such a period would show high susceptibility to even very weak forces. Many experiments by Persinger, Ossenkopp and their colleagues, (e.g., Persinger et al., 1973) have indicated that rats exposed during various stages of their prenatal development to 0.5 Hz RMFs with intensities ranging from <1 to 30 gauss, show significant changes in their behaviour relative to controls or sham exposed animals. RMF-exposed rats show-

ed less open field activity, greater defecation, increased acquisition of a conditioned suppression paradigm, and thyroid-testicle weight changes. The effects were dose dependent and a function of developmental period at the time of exposure. Rats exposed to 0.5 Hz RMF-fields from 2 days before birth to 5 days after birth show similar behavioural-physiological differences as adults. Unpublished data collected by Persinger and Lafrenière indicate that adult changes associated with RMF-exposure during day −2 to +5 of development can be diminished to control values by re-exposing these subjects as adults to the same field.

In many respects, the problems and techniques which are involved with pharmacological research can be usefully applied to magnetic field research. Dose (intensity) or analog (frequency) dependent response curves are convincing data. As with drug reactions, the antecedent operations or conditions performed on the organism may determine not only the direction but extent of the effect. If the autonomic nervous system is involved primarily with biomagnetic phenomena, then exposure of the animal to extraneous conditions which stimulate this system would affect the pattern by which the magnetic field exerts its influence. Operation of a law of initial values would be a significant factor in these reactions. Age, sex and perhaps most of all the degree of autonomic lability would also be important variables.

Magnetic field ambients from both natural and man-made sources have been rarely considered in biomagnetic research. Superimposition of the experimental fields and testing area upon locally produced magnetic irregularities could have adversive effects. Tromp (1968) has measured the presence of unusual field characteristics in dwellings (with steel supports) and in areas of low soil resistivity. Interfering magnetic transients or statics can come from test equipment itself. All these factors could alter the sensitivity and response of animals exposed to experimental magnetic fields.

To any proficient scientist a repeated and measurable change of behaviour or physiology associated with the experimental presentation of magnetic fields should be sufficient stimulation to maintain further interest and investigation. The pre-isolation of a physical mechanism is not an absolute necessity to continue research. Unfortunately not all scientists agree with these statements but make the acceptability of a phenomenon contingent upon the prior existence of a "feasible model" or in terms of mechanisms known to date—even if they are not applicable. Such caution certainly inhibits the undesirable members of the academic community from publishing poorly collected or belief-influenced data, but it also delays the acknowledgement of new phenomena. Researchers who are interested in the effects of magnetic fields, specifically those associated with near-natural intensities and frequencies, will face this opposition.

Magnetic fields of different characteristics can be used as a tool to cross cut a variety of discourse levels. Magnetic field effects can be measured by molecular, physiological and behavioural indices. Perhaps the study of magnetic fields, both biogenic-like and high intensity, will allow us to understand more clearly how molecular-biochemical-physiological-electrical-behavioural sequences are normally linked. Perhaps the study of their effects will give us some insights to the complex substrates of animal behaviour. On the other hand, magnetic-associated effects may be so varied and unrelated that

interdisciplinary systematic investigation will be impossible. The young researcher interested in magnetic effects should be cognizant of these possibilities and have sufficient endurance to consider the multitude of variables involved. He should realize that the study of magnetism and behaviour is a problem which cannot be contained within one discipline but requires accurate knowledge from many, many areas.

REFERENCES: see pp. 284-285.